Scientists demonstrate first experimental evidence of non-Hermitian edge burst in photonic quantum walks

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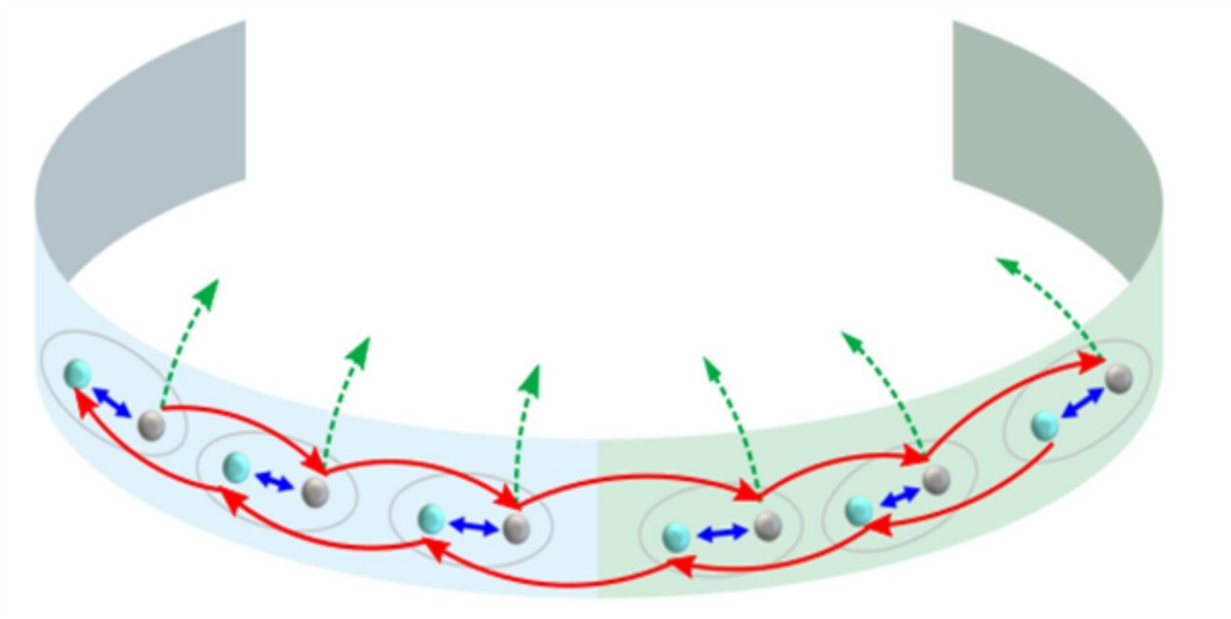


Domain-wall geometry of the non-Hermitian quantum walk dynamics. Credit: Prof. Peng Xue.

In a new *Physical Review Letters* study, scientists have demonstrated the first experimental observation of non-Hermitian edge burst in quantum dynamics using a carefully designed photonic quantum walk setup.

The increasing interest in non-Hermitian systems reflects their role in understanding real-world systems that are characterized by dissipation, interactions with the environment, or gain-and-loss mechanisms.

They reveal new physics not seen in Hermitian systems, like boundary localization, which can have interesting applications in photonics and condensed matter physics. The researchers in the PRL study focused on a non-Hermitian skin effect (NHSE), where a system exhibits unique behavior at the edges or boundaries.

Phys.org spoke to co-authors of the study, Prof. Wei Yi from the University of Science and Technology of China, Prof. Zhong Wang from Tsinghua University, and Prof. Peng Xue from Beijing Computational Science Research Center.

Speaking of their motivation for studying non-Hermitian systems, Prof. Xue said, "One of the key incentives for its flourishing progress was the discovery of the NHSE." The term NHSE was coined by Prof. Wang and his colleague in an earlier PRL study, and the team has been actively working on it since its discovery.

Prof. Yi added, "While the NHSE has revealed intriguing static properties (such as energy spectrum) of non-Hermitian systems, we became very curious about the possible existence of novel dynamic phenomena with extreme sensitivity to boundaries."

Real-time dynamics

In non-Hermitian systems, operators are not equal to their Hermitian conjugates. As a result, the eigenvalues are complex, which gives rise to distinctive phenomena like the NHSE.

In NHSE, the eigenstates of a non-Hermitian system accumulate at the

edges or boundaries. This is different from bulk properties seen in Hermitian systems. NHSE is typically seen in open systems with gain or loss in energy, i.e., Hamiltonian.

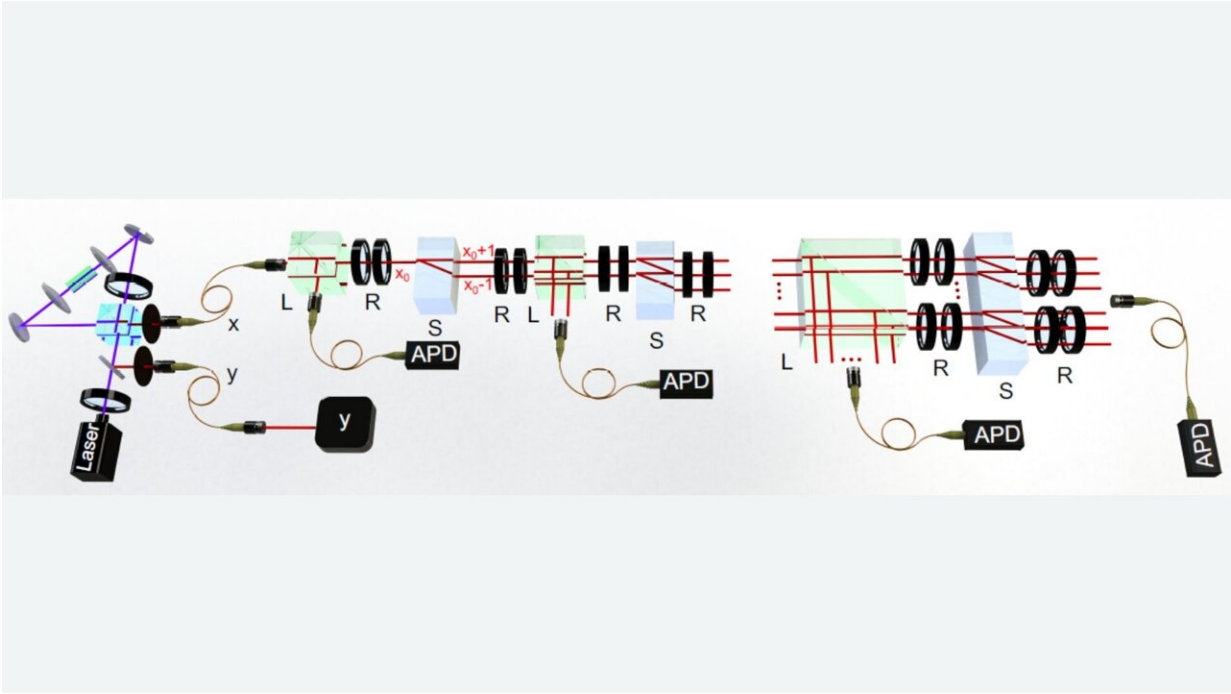
Previous studies have studied this effect in static conditions, meaning that the properties of the system, like the Hamiltonian, do not change with time. However, Wang and his team concentrated on examining how the edge dynamics change over time.

"While previous studies focused on more static aspects (such as the energy spectrum) of non-Hermitian systems, our work unveils an intriguing dynamic phenomenon," said Prof. Wang.

Studying real-time dynamics can offer insight into real-world systems where the Hamiltonian evolves over time, reflecting changes in the system's energy and behavior.

One-dimensional quantum walk

For investigating the real-time edge dynamics in non-Hermitian systems, the researchers used a setup featuring a one-dimensional quantum walk with photons. Each step or movement is determined by a quantum coin flip, which introduces probabilistic movement.



Experimental setup for non-Hermitian edge burst in quantum-walk dynamics. Credit: Peng Xue.

A boundary or wall was part of the experimental setup, segmenting the system into two regions, where each region followed different rules for the quantum walk.

The quantum walk of the photon was managed with the help of different optical tools, including beam splitters, wave plates, and beam displacers.

Their goal was to study how the loss mechanism works at the boundary, for which they use partially polarizing beam splitters. This introduces photon loss, which they can then measure when the photons exit the system.

Through this measurement, they are able to determine the occurrence of

loss at various positions and times, which sheds light on the dynamics of the edge. Additionally, the researchers explored how different initial conditions (where the photons start) affect the edge dynamics of the non-Hermitian system.

Edge dynamics

The researchers detected an increase in the probability of photon loss at the boundary, confirming the existence of the non-Hermitian edge burst. However, they found this only occurs when two conditions are simultaneously met.

The first condition is the non-Hermitian skin effect—where the eigenstates accumulate near the edges—must be present. Secondly, the imaginary gap in the energy spectrum must be closed. This means the difference between the real and imaginary parts of the energy spectrum decreases.

The necessity for the two conditions to be simultaneously met highlights the interplay between static localization (NHSE) and dynamic evolution (imaginary gap).

Prof. Yi explained, "These phenomena provide a complete view over the correspondence between the non-Hermitian topology of the bulk and sharp features, both static and dynamic, at boundaries."

They also concluded that the initial position of the photos plays a role in the edge burst becoming pronounced. The probability of losing a photon at the boundary wall is reduced when the photon begins further from the boundary, compared to when it starts near it.

Successfully mapping the edge burst's full time evolution, the researchers showed that it occurs precisely when the particle reaches the

boundary. Further, they showed that the phenomena are consistent even when the initial position of the particle varies.

Future work

The experimental observation of real-time edge bursts in non-Hermitian systems reveals a novel interplay between topological physics and dynamical phenomena.

According to Prof. Wang, this could open new avenues for research in this field. He said, "The spatial and spectral sensitivity of the edge burst opens the avenue of exploring localized light harvesting or quantum sensing using the phenomenon.

Prof. Xue added, "Our work paves the way for studying the rich real-time dynamics in non-Hermitian topological systems, hinting at the possible existence of other universal scaling relations in non-Hermitian systems."

According to the team, the edge burst effect could be practically utilized for harvesting light or particles at precise locations, with implications for photonics and other wave-based fields.

More information: Lei Xiao et al, Observation of Non-Hermitian Edge Burst in Quantum Dynamics, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.070801. On *arXiv*: DOI: 10.48550/arxiv.2303.12831